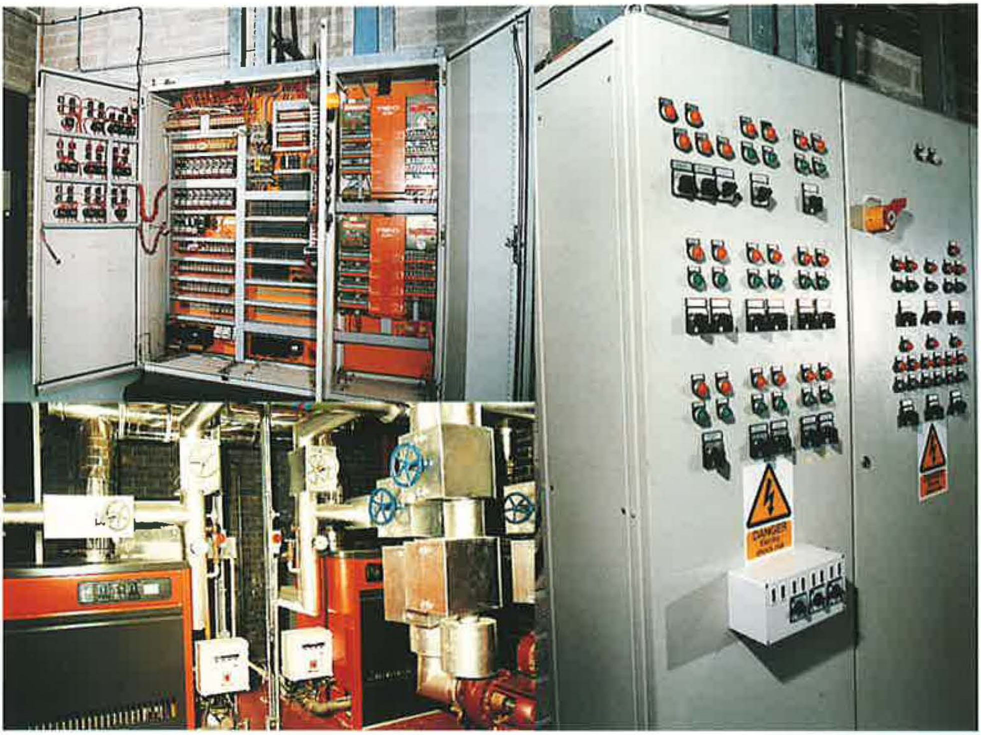
Department of the ENVIRONMENT

FUEL EFFICIENCY BOOKLET 10

Controls and energy savings



BEST PRACTICE PROGRAMME

ENERGY EFFICIENCY

BEST PRACTICE PROGRAMME

The views and judgements expressed in this Fuel Efficiency Booklet are not necessarily those of the Department of the Environment, ETSU or BRECSU.

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INTRODUCTION

1 INTRODUCTION

The cost of operating and maintaining a heating and ventilation system represents a significant proportion of the total running cost of a building. Good control of these systems will minimise energy and maintenance costs while providing comfortable conditions for the building occupants. Correct specification of the building control requirements is essential to ensure that capital spending is matched to the potential benefits of the system. Furthermore, the Building Regulations require a minimum level of control system in all intermittently occupied buildings.

This booklet is intended as a brief guide to the different types of heating and air conditioning control systems, from the simple thermostat to the more complex interactive digital controllers. It gives guidance on choosing the most appropriate control system for a given application, taking into account building size, occupancy and type of heating system. The importance of correct installation and maintenance must also be stressed, and these points are covered in Sections 13 and 14.

Detailed documentation on the subject covered in this booklet is referenced in the text and listed in Section 16.

2 FUNCTION OF CONTROL SYSTEMS

Controls perform two basic functions:

- switching equipment between two states (usually 'on' and 'off');
- varying the output of an item of equipment to maintain the value of a variable (usually, but not necessarily, a constant).

The simplest means of achieving energy savings is to switch plant off when it is not required. This can be done using very basic controls such as on/off switches, which rely on building occupants using them correctly. The introduction of new sensing devices, more controllable plant and microprocessor-based communicating devices has enabled more dependable energy savings to be achieved. A good principle, however, is to avoid complicating a system unnecessarily - for a particular application, a simple thermostat may be the most effective form of control. This principle holds for all sizes of building and all types of heating and ventilation system.

3 ENERGY SAVING POTENTIAL

The minimum level of heating and air-conditioning control in new buildings is governed by the Building Regulations (see Appendix 1). Achieving this level of control in a building that currently has poor or no controls will make considerable savings, but up to 20% more energy savings can be economically viable through investment in more sophisticated control systems. A rule-of-thumb cost/benefit assessment can be made using Table 1, which shows the concept of Controls Banding. Band 0 is the minimum required in the Building Regulations for new installations. Bands 1 and 2 are more costly installations but also more energy efficient.

Levels 1, 0 and -1 apply to control on all wet heating and hot water systems, whatever the heat output. Level 2 applies only to control on systems with heat output greater than 100 kW.

Section 12 details the equipment required to reach these levels of control.

Numerous Case Studies have been undertaken by the Building Research

GENERAL GUIDANCE

Control Band	Capital cost increase over Band 0 base	Usage, compared to Band 0 base	Return on cost of controls over Band 0 base	Comments
2	100% - 200%	20% less	2 - 4 years	Highly recommended for minimum energy usage
1	50% - 100%	10% less	1 - 2 years	Recommended for cost effective energy savings
0	0%	0%	N/A	Minimum for cost effective energy savings
-1	N/A	up to 50% more	N/A	Does not meet Building Regulations since 1985

Table 1 Rule-of-thumb cost/benefit assessment: Controls Banding

Establishment, which have demonstrated the value of energy savings achievable through the installation and use of well-designed control systems in a range of building types. For example, installing an electronic multi-zone heating controller has enabled the River Wyre public house in Lancashire to tailor heating load to occupancy levels and save around £610 per year. This was combined with a range of other measures which reduced the pub's energy use by 30% (see Good Practice Case Study 52 - *Energy Efficiency in Public Houses: Refurbishment of a Large Rural Inn* - for further details).

4 GENERAL GUIDANCE

The most important function of a heating or ventilation control system is to maintain an appropriate environment for the building occupants. To be able to do this it is essential to assess correctly the needs of the different occupants.

Occupancy and temperature control

The occupancy periods of most buildings are predictable, but may not be the same for all rooms within the building, typically conference rooms, lecture rooms and so on. Where flexitime is worked, a room will have varied occupancy throughout the day.

Similarly, different areas will have different temperature requirements depending on the activities engaged in. Store rooms and corridors can be kept at lower temperatures than offices. Areas where people are engaged in physical work or sport should also be cooler.

A problem occurs in areas of mixed activity. If the temperature is kept sufficiently high for desk workers to be comfortable wearing only light clothing, it will be too hot for those doing physical work and should be lowered. Sedentary workers can always put more clothes on, but the scope for manual workers to remove clothing is limited. Diplomatic skills rather than control technology are required in these instances.

The existence of varying needs demonstrates the necessity for adequate zoning. Each discrete

CONTROL OF CENTRAL HEATING

area should be able to be controlled according to its needs. Inability to do this will lead to considerable energy wastage.

In some areas of a building, such as computer rooms, tight control of the environment is required. For normal use, slight variations in ambient temperature will go unnoticed and control within a temperature band of around 2°C will be adequate.

Individual building occupants may feel some resentment that their environment is being controlled remotely. In the right circumstances, local set-point adjusters can not only improve comfort conditions, but also give the occupants a sense of well-being by giving them some control over their working conditions. The adjustment should be limited to ± 2°C. Caution is needed, because in the wrong circumstances this control can become very contentious.

Sensor location

The position of the space heating sensor should be selected with some care. If the building has only one compensated heating circuit, then the sensor should be located in a north-facing room approximately half-way up the building. If the building has a number of heating circuits and a sensor needs to be located in a south-facing room, it must not be exposed to direct sunlight. The room chosen should be representative of the general activity of the building. It should not be a room seldom occupied or a room with abnormal heat gains from computers, photocopiers, etc. The sensor should be located where there is a free flow of air around it and certainly not above a radiator.

A problem can arise with the design of new buildings, particularly if the building occupier is not known at the time. The room temperature sensors will be located in what appear to be appropriate places, but they may prove quite unsuitable for the occupants' needs; indeed, the new occupants may even ignore their presence. It is not unknown for bookshelves to be erected around room sensors, or for cupboards to be placed in front of them.

5 CONTROL OF CENTRAL HEATING

The controls covered in this section apply primarily to wet central heating systems. Warm air and electric heating controls are covered in Sections 6 and 7 respectively.

Time control

If the occupancy profile of a building is known in advance, then the period of operation of the heating system can be controlled by a simple time switch or an optimiser.

Time switches

The traditional electromechanical time switch is often the most appropriate for small systems, being cheap, reliable and simple to adjust. For more complex applications, electronic or microprocessor-based devices are available with multiple outputs, greater flexibility and a programming facility for typically a year in advance. Time switches should have a resolution of 15 minutes or less for effective operation, and an override facility for low-temperature protection (see Section 5).

Optimisers

An optimiser is basically a device incorporating a time switch, which switches the plant on at such a time that the room temperature reaches the

CONTROL OF CENTRAL HEATING

required value at or just before the predetermined occupancy start time. Most optimisers calculate the start-up time from a combination of space and ambient temperature sensor outputs. Low cost optimisers may use space temperature only, but these have the disadvantage that for buildings occupied for a normal five-day week, they tend to switch the plant on too late on Monday mornings because they are unable to cater for the additional heat loss over the weekend. This can be offset to a certain extent by setting an earlier occupancy start time for Mondays. In this country, most optimiser models provide optimised start for heating only, but optimised start for cooling and also optimised stop can be provided. The operation of an optimiser is shown in Fig 1.

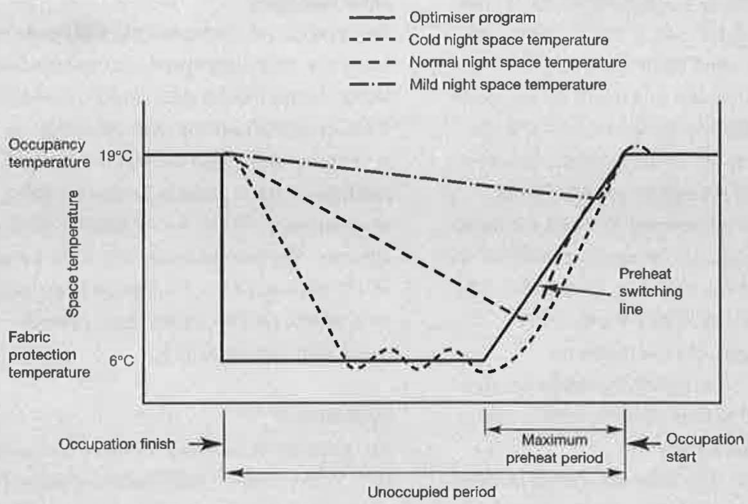
Building Regulations specify that an optimiser or optimum start program is required for buildings with a space heating load of more than 100 kW.

For new installations or retrofits, the low additional cost of a simple optimiser will generally be rapidly recouped via reduced energy costs on systems with heating loads as low as 30 kW, even when the cheaper heating fuels are used. With more expensive heating fuels, optimisers may be viable at lower heating loads.

Variable Occupancy

Rooms that are only occupied occasionally or for short periods need separate controls. An 'on/off' switch will suffice if users can be trusted to switch off when they leave the room, but this is often not the case. A simple semi-manual option is to have a push button 'on' switch associated with a timer set to switch off again after an appropriate period.

Fig 1 Optimiser function



CONTROL OF CENTRAL HEATING

Temperature control

In addition to controlling the time of operation of a heating system, it is essential to be able to maintain the ambient temperature of the controlled environment.

Compensators

For buildings other than dwellings, the Building Regulations require that the temperature of the heating system is regulated according to outside temperature. This is achieved by using a compensator which adjusts the flow temperature in the heating circuit as the outside temperature rises or falls. The most common relationship, a straight line slope, is shown in Fig 2. The maximum flow temperature is constrained by the boiler specification and the minimum flow temperature by the ambient temperature of the water system.

The position of the slope can be adjusted to take account of internal temperature, solar gain or wind chill, by means of appropriately positioned sensors.

Some compensators use a non-linear relationship which relates internal temperature to external temperature more accurately. This is particularly useful in buildings with large single-glazed areas, to reduce the discomfort caused by down draughts when the outside temperature falls below 10°C.

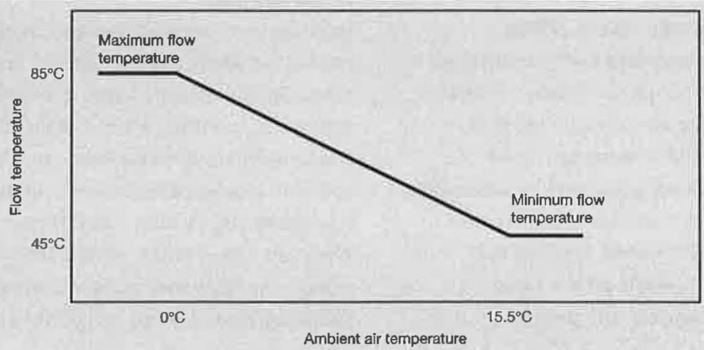
Self-adaptive compensators 'learn' the impact of the building characteristics on internal temperature, and adjust the flow temperature based on the flow temperature/outside temperature relationship of previous days.

Compensated circuits are usually set up via the pipework and valve configuration in the heating circuit, but it is also possible to compensate the boiler directly. In practice, most compensators are combined with an optimiser in the same unit, which also provides facilities such as night set-back of space temperature, frost protection, wind and solar influence detectors etc.

Room temperature

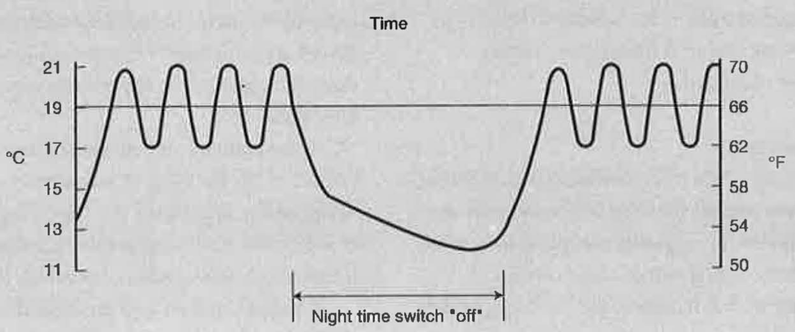
Room thermostats are commonly used for control of domestic heating systems. They may

Fig 2 Compensator slope



CONTROL OF CENTRAL HEATING

Fig 3 Simple on-off thermostatic control cycle with time switch



also be used in non-domestic applications, although for large buildings, zoning and the correct location of thermostats are important. Thermostats control the operation of the boiler and/or pump, switching it on or off when space temperature limits are reached. The switching pattern is shown in Fig 3.

It is common in small systems for the thermostat to switch the central heating pump only, leaving the boiler to cut out on its high-limit switch. However, greater energy savings can be achieved by switching the boiler as well as the pump.

Thermostatic Radiator Valves (TRVs)

TRVs sense space temperature and throttle the flow accordingly through the emitter to which they are fitted. They are normally fitted to radiators but can also be fitted to convectors. TRVs are available with either built-in or remote temperature sensors and with restricted plug movement for non-domestic applications.

Whilst built-in sensors are the most convenient, it is essential that they are located correctly so that the convection from the radiator or pipes does not affect the sensing head. The sensor should be mounted horizontally at the top of the radiator, away from cold draughts or direct sunlight. It is also important to have a free flow of air around the sensor and for it to be easily accessible.

TRVs can provide very energy efficient control. In a large room with several radiators and a variety of activities and heat gains, control of individual radiators can provide the correct level of localised heating.

Boiler controls

Inadequate or incorrect application of boiler control can easily add 15 - 30% to fuel consumption compared with a well-controlled system. In particular, control of multiple boilers is generally poorly understood, as a consequence of which many existing systems are mis-configured and in some cases uncontrollable. The main aim of boiler control should be to reduce avoidable wastage to a minimum whilst providing the necessary output as required.

CONTROL OF CENTRAL HEATING

Firing control

The objective of boiler firing control is to control the burner to maintain the desired boiler flow (outlet) temperature.

Burners can be on/off, high/low or modulating. On/off and high/low/off burners are controlled by thermostats and give some variation in flow temperature due to the thermostat switching differential necessary for stable control. Modulating burners are controlled via temperature sensors and controllers, and provide near constant boiler flow temperatures. Boiler firing controls are normally packaged with the boiler and must remain in operation for multiple boiler installations. Where boilers are directly compensated, or multiple modulating boilers are used, the boiler firing control may be overridden to stop firing or reduce output.

Sequence control

Boiler sequence control enables only the number of boilers that are actually required to meet the system demand, and therefore provides stable operation of those boilers in an energy efficient manner.

The order of boiler operation is normally manually selected, but can be automatically rotated on a time or usage basis to share the duty between boilers.

Loading controls

Boiler loading control governs the number of boilers operating, so that only those boilers whose output is required to satisfy the system load are hot. All other boilers should be cold or cooling such that the standing losses and energy usage are minimised.

Boiler loading control requires very careful hydraulic design and system balancing to be effective.

Frost and fabric protection

Protection against condensation and freezing is an important function of a heating control system. This is normally provided as part of an optimiser's functions, but where an optimiser is not used, or does not provide the required functions, additional controls may be required. Separate protective means will be required for any unheated areas containing items which can be damaged by low temperature.

Sensors for fabric protection should be located in the part of the building which is likely to cool fastest or is the most vulnerable to damage; this is normally a north-facing corner on the top floor. Where more than one internal temperature sensor is installed, and a programmable or other suitable controller is used, the lowest of the sensor readings may be used. Fabric protection should maintain the building at the minimum required temperature, normally between 4°C and 10°C. The lower the setting the less energy is used.

Frost protection of pipework is normally achieved in two stages. The first stage runs the system pumps when the external ambient temperature drops to 2 - 3°C; the second stage starts the boilers when the system return water temperature drops below 5°C. Insulation and residual internal heat should ensure water temperature is normally above ambient. The boilers should be enabled until a return water temperature of 50 - 60°C is reached to prevent boiler cycling and flue gas condensation; this will be achieved in most systems without additional controls.

CONTROL OF WARM AIR AND ELECTRIC HEATING

Separate frost protection of pipework is required where pipework is exposed or likely to be subjected to freezing temperatures. It is especially important in well-insulated buildings where boilerhouse plant can freeze up before the building calls for heat.

6 CONTROL OF WARM AIR HEATING

Warm air systems provide a more rapid response than wet heating systems, so good control is essential for maintaining comfortable conditions and allowing energy efficient operation.

The type of control depends on the mode of operation. Full fresh air heaters are used to provide a minimum number of hourly air changes. Hence the air fans should run continuously and temperature is controlled by varying the output of the burner.

For recirculating air systems, both the burner and fans are controlled. This may be either via a thermostat controlling on/off operation of the burner or, preferably, by modulating control of the burner with respect to space temperature. The operation of the burner should be interlocked with the fan operation to ensure air is flowing before firing.

7 CONTROL OF ELECTRIC HEATING

Electric heating systems generally consist of a mix of storage heaters and direct-acting heaters. The storage heaters provide most of the heat required at off-peak rates, with direct heaters providing top-up heating as required at peak rates. Direct heating alone is normally only used in very intermittently occupied buildings or parts of buildings.

Direct electric heating at peak rates can be twice as expensive to run as off-peak heating, and consequently inappropriate selection or operation of controls will result in significant cost penalties.

Most electrical heating emitters have in-built thermostatic control which has the advantage of local control at each emitter. However, as the thermostats are built-in, they are normally poorly located for sensing representative space temperatures. In general, adjustments to suit the application can easily be made.

Given the high cost of daytime electric heating, considerable savings can be made by restricting access to the heating controls. This can be done by pre-setting the controls and removing or fixing covers over the switches. Accessible run-back timers can then be provided, with set limits, to allow users to boost the heating.

Centralised time switch control of a number of electric heaters is difficult to achieve unless a special ring main is used. The alternative is to use local plug-in time switches but these are susceptible to misuse and pilfering. To comply with current (1990) Building Regulations, for installations over 100 kW, the heaters must be controlled by an optimum start programme and therefore a separate controllable ring main should be used.

Portable heaters

Portable heaters are normally fitted with built-in thermostats. If not, it is possible to use a plug-in thermostat at the mains socket. Run-back timers can be used to limit the hours of use.

Portable electric heaters should not normally be used to supplement a wet heating system, as they can lead to control problems. The additional heat can often cause the wet heating

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system to turn off, or reset to a lower temperature, thereby necessitating greater use of the electric heaters.

Storage heaters

Storage heater systems are generally designed to provide 90% of the heating requirement using off-peak electricity. The remainder is usually provided by direct heaters.

Storage heaters should only be used where low cost off-peak electricity is available. They are not generally appropriate for buildings with high daytime electricity usage, as the extra cost of the daytime use may outweigh the off-peak savings.

Natural convection storage heaters (without fan assistance) are controlled by adjusting the dampers to avoid too much of the heat being provided during the morning, and then tailing off during the day. The dampers may need to be adjusted several times during the year. Some storage heaters have a boost control which allows extra heat to be given out for short periods.

Fan-assisted storage heaters are far more controllable than natural convection units, because the heat output can be controlled by a room thermostat. As a result, heat not used will be stored until the following night, thus reducing the charging required.

Optimisers are available which predict the charge required based on the previous day and overnight temperatures. These must be used for storage heating systems of more than 100 kW, and are also recommended for smaller systems.

Underfloor heating

Special controllers must be used to provide compensated control of the temperature of electric underfloor heating. A maximum temperature limit must be included to prevent overheating of the floor which can result in discomfort and possibly structural damage.

8 CONTROL OF HOT WATER SYSTEMS

Many hot water systems are the source of major energy wastage. This is particularly true where space heating and hot water are heated from the same source, in which case savings of 90% of energy use can be achieved via improved control during the summer. Control is also important to avoid health risks, particularly legionnaires' disease, and scalding.

The requirements of the relevant water authority and the water by-laws must be taken into account for all hot water systems.

Avoiding legionnaires' disease

Legionnaires' disease can have fatality rates of 10% in susceptible groups of people. It is caused by legionellae bacteria being breathed into the lungs.

The basic control premises for avoidance of legionella infection are:

- maintenance of outflow temperature at 60°C ± 2.5°C;
- maintenance of return water temperature from circulation above 50°C.

Further reading

Further guidance on this topic can be found in:

- CIBSE Technical Memorandum, TM13 - *Minimising the Risk of Legionnaires' Disease.*
- DHSS Code of Practice - *The Control of Legionella in Health Care Premises.*
- Health and Safety Commission Approved Code of Practice - *The Prevention or Control of Legionellosis (including Legionnaires' Disease).*

CONTROL OF HOT WATER SYSTEMS

- Health and Safety Executive: HS(G)70 - *The Control of Legionellosis Including Legionnaires' Disease.*

Minimising standing losses

Up to 90% of the energy used for the provision of hot water can be wasted due to heat loss and inefficient generation. Many buildings have oversized storage cylinders. These are heated, via a distribution system, from boilers which during the summer months are far too large for the load. A number of smaller boilers with loading control reduces losses, as does a boiler sized for the hot water load with summer/winter changeover. Even so, the energy use associated with distribution is still high. Considerable savings can be made via totally segregated and distributed generation of hot water.

Time control

In intermittently occupied buildings, hot water storage systems should be time controlled, as required by the current Building Regulations. To avoid legionellae formation, one of the following should be ensured:

Water temperature is maintained at a minimum of 60°C - this can be very wasteful if water is recirculated.

Water temperature is elevated to 70°C for a period prior to occupancy - this requires use of a dual-setting control thermostat with time switch or a proprietary packaged control. If no local low temperature mixing systems exist, times should be set such that the water temperature has cooled to safe levels prior to the start of occupancy.

Temperature control

Control of storage cylinder temperature should be with an immersion thermostat two-thirds of the way up the cylinder, and a high limit thermostat at the top of the cylinder or in the outlet. To ensure the water temperature is high enough to prevent legionellae infection and to avoid stagnation, the water should be recirculated around the tank and pumped around the distribution system.

Where there is a risk of scalding, water should be stored at higher temperatures and mixed with cold water near the point of use via thermostatic control valves.

Direct-fired water heaters

Direct-fired units heat the water immediately before it is used, usually via a gas or oil burner. The temperature should be controlled with thermostats at the top of the unit near the outlet. These controls are generally provided as part of a packaged unit.

Where hot water use is intermittent, additional savings may be made with gas-fired water heaters by the use of flue dampers. The flue dampers are controlled to open during the firing cycle as required. Manufacturers claim that up to 50% energy savings can be made in certain applications, such as sports centres.

Electric water heaters

Immersion heaters are temperature controlled via built-in thermostats and should be time controlled as required. Top entry immersion heaters are not recommended, because only the top of the tank gets hot.

CONTROL OF AIR CONDITIONING SYSTEMS

To minimise the use of peak rate electricity:

- storage cylinders should be sized such that 90% of consumption can be on night rate electricity;
- the water temperature thermostat should be set to control the water storage temperature at 60°C;
- run-back timers should be installed to enable economic provision of peak rate top up.

Point of use water heaters contain in-built variable temperature control. As there is no storage capacity in the system, no additional control is required.

9 CONTROL OF AIR CONDITIONING SYSTEMS

In an air conditioned office, up to 40% of the building's energy bill may be attributable to the air conditioning system. Good controls can significantly reduce the cost of operating the system. Selection of the appropriate system and energy conscious design are also very important. These are covered in Good Practice Guide 71 - *Selecting Air Conditioning Systems: A Guide for Building Clients and their Advisors.*

An air handling unit may require controls for a range of variables: heating and cooling; humidity; pressure; air flow volume; and fresh air supply. A prime consideration is how wide a tolerance of the controlled variable is acceptable. Temperature control of ± 1°C is usually quite adequate. A far greater tolerance is acceptable for relative humidity, which is usually controlled within the range 40 - 70%. Occupants are unlikely to notice changes within these bands. Achieving tighter control, particularly for temperature, will waste energy, as both the heating equipment and the cooling equipment will be over-used.

Energy is also wasted when air is first cooled and then reheated to maintain the correct temperature and humidity. This can be minimised by making optimum use of outside air for cooling, through a technique known as 'enthalpy economisation'.

Pumps and fans consume a large proportion of the energy used in air conditioning. Energy can be saved by varying the air volume according to needs. Generally, air handling units are designed to cope with maximum load conditions. In practice, air volumes can be reduced when heating and increased when cooling. In buildings which have large variations in occupancy level, considerable savings may be achieved by matching the ventilation rate to the number of occupants. It is not normally practical to count the number of people present in an area automatically, but a common method is to ascertain this using an air quality sensor. This sensor measures the level of CO_2 in the return air ducts and regulates the ventilation fans accordingly. This type of control is particularly appropriate in buildings such as cinemas, sports complexes and department stores.

An example is given in the Project Profile 172 - *Ventilation Control using* CO_2 - which details such control at a bingo and social club, and a cinema owned by Rank Leisure.

The mechanism for reducing air volumes has traditionally been to use dampers or inlet guide valves. Variable speed drives (VSDs) are an alternative, cost-effective means of achieving energy savings, because they use less power for the same volume of air below peak load. Fig 4 shows the energy use characteristics of the three methods. VSDs can also be effective for pumps and Fig 5 shows the comparison between a

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variable speed pump and a pump with throttle control using a two port valve.

10 BUILDING ENERGY MANAGEMENT SYSTEMS (BEMS)

BEMS are computer-based systems which automatically monitor and control a range of building services such as heating, air conditioning, ventilation, boilers, and lighting. An important part of their function, beyond controlling environmental parameters, is to provide data on energy performance to enable energy savings to be targeted.

There are two main types of BEMS: centralised and distributed intelligence. Centralised systems control all the connected site services from a single computer unit. These are most appropriate for large commercial or industrial buildings, such as hospitals with over 500 beds, motor factories and airport terminals.

A more recent development are distributed intelligence systems. These comprise a number of local intelligent outstations which each control a small building, part of a large building or a particular service. The outstations feed data back to a central unit so that the collective information can be analysed. This type of system is generally used for a group of small to medium-sized buildings under common ownership, such as schools, hotels, pubs and chain store premises.

Energy efficiency improvements of 10 - 20% can be achieved by installing a BEMS, compared with independent control of individual services. However, there are a number of factors that may limit the actual savings achievable and these must be addressed before a system is installed.

Fig 4 Energy use of air volume control methods

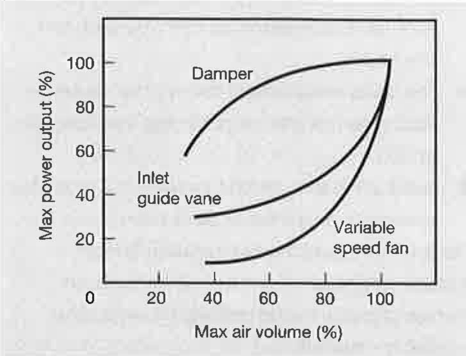
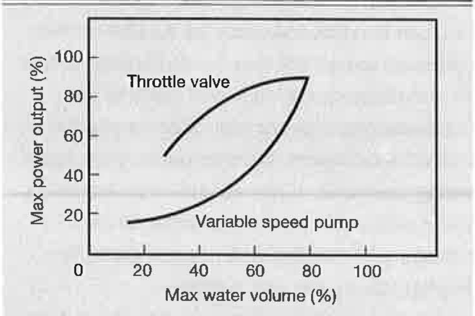


Fig 5 Comparison of energy use using VSDs and throttle valves



- *Suitability of existing buildings and equipment:* For a BEMS to work effectively in an existing building, it must be possible to zone the heating, ventilation and lighting systems according to the use made of different areas. The plant must also be flexible enough to respond to the changes required by the system. Problems often occur in buildings that have changed their function over the years without changing the services systems.
- *Correct operation and maintenance:* If existing equipment is not being properly

maintained or controls are incorrectly set, then substantial savings can be made by rectifying these first. Once this is done, installation of a BEMS may no longer be cost-effective. There is little point in having a BEMS if its major function is to demonstrate how bad or inappropriate the building services are.

- *Staff involvement and commitment:* It is essential that the staff who will be operating and maintaining the system are committed to its success. They should be involved from the start of the project and be kept informed of its progress. They should also be aware of exactly what the system will do, and should decide how the information produced will be used.

To make full use of the system, staff need to feel relaxed and confident, and this can only come with good training and experience. Proper provision for training all staff who will use the system should be included in the contract. Whilst this may seem expensive, inefficient use of the system through lack of training is often more costly. All reputable BEMS suppliers not only provide but also encourage training, as it is in their interest that the system works well.

Further information on BEMS is given in the Department of the Environment (DOE) booklet, Energy Technology Series 1 - *Energy Management Systems* - and in (DOE) Information Leaflets 20 and 21.

11 INTELLIGENT BUILDINGS

'Intelligent Building' is the term often used to describe buildings with a high level of computerised control of a large number of operations, and integration of different control systems. Integrated systems are being developed in two stages. The first stage is to link all building management systems, such as energy management, security and disaster prevention systems. The second stage is to link the building management system to office automation systems and to external telecommunications systems.

It is estimated that the technologies required for fully integrated systems could cost up to 50% more than the cost of a conventional building without intelligent building technologies, and between 15 - 20% more than a building with non-integrated systems. This additional expenditure is justified on the basis of cost savings in energy use, efficiency and adaptability. Integrated systems are claimed to offer further cost benefits in terms of reduced space for installations and greater centralised group control and management.

12 CHOICE OF CONTROL SYSTEMS

While there are a large number of control devices available, there are basically three levels of complexity:

- Traditional hardwired controllers are simple, reliable and easy to use, but are inflexible and limited.
- Microprocessor-based, pre-programmed non-communicating controllers are gradually replacing hardwired controllers and there are also a number of hybrids of the two. They normally have touchpads rather than knobs and switches, but are usually reasonably easy to understand and tend to have greater flexibility and more output than the hardwired controllers. Some are in fact control systems in themselves, being, for

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example, combined optimisers and compensators with extra switching and monitoring facilities.

- Microprocessor-based fully programmable communicating controllers, often referred to as Direct Digital Controllers (DDC), are what their name implies and form the basic control unit in a BEMS, although they can be used by themselves. They are extremely flexible and can be programmed to perform complex interactive control functions. They have to be programmed by a trained person using a computer, although some manufacturers supply a hand-held programming tool which will allow minor changes to be made easily, such as set-points or stop/start times.

As a general rule, it is best not to complicate a system unnecessarily. However, the more complex systems give the greatest potential for energy savings provided they are correctly applied and maintained. If several non-communicating controllers are used to control different variables it is essential to ensure they do not interfere with each other.

Before deciding on the appropriate level of complexity required, it is worth considering the following points.

- *Size and complexity of the building:*
  For small individual buildings or those with a uniform pattern of occupancy, it is unlikely that investment in a BEMS will be economic. Pre-set or self-adaptive controls, with an override option for out-of-hours working, should provide an appropriate level of comfort and energy savings over a poorly controlled system.
- *Existing Equipment*
  The existing heating or ventilation equipment may be unable to respond effectively to the level of control proposed. It may be necessary to invest in new equipment before savings can be realised through sophisticated controls. Similarly, it should be ensured that it is possible to zone the building as necessary.
- *Staff Available*
  A complex control system needs suitably trained people with the time available to manage it and use the data produced. If no-one is available, it is unlikely that the potential savings of the control system will be achieved.

Combination of controls

All buildings require a combination of controls for space heating, water heating, boilers, distribution systems and so on. Table 2 shows the combinations of equipment required to reach the different Controls Banding levels (see Section 3) for a heat output greater than 100 kW. It also shows the commissioning, documentation and maintenance requirements to ensure correct operation. Table 3 gives the same information for systems less than 100 kW.

13 DESIGN, SPECIFICATION, INSTALLATION AND COMMISSIONING

A high proportion of faults which occur with building control systems are due to poor design, inadequate specification, incorrect installation or incomplete commissioning. It is vital that adequate finance and time is set aside in a project to allow these areas to be covered in the detail required.

Table 2 Heating controls: Output greater than 100 kW

Band Level	Time Controls	Boiler Controls	Disribution System Controls	Space Heating Controls	HWS Controls	Commissioning	Documentation	Maintenance	Marginal ROI (Return on Investment) & Energy Usage	Comments
2	Optimiser plus time control of zones where appropriate. Time control of HW storage.	Boiler loading control. Air & water flow eliminated through off line boilers except if high efficiency/ condensing boilers. More sophisticated control strategies where appropriate. Interaction with space control.	Compensated with space temperature reset. Separate compensated circuits for orientation structure & occupancy where appropriate. Interaction with space control.	Interactive control of rooms/ emitters where appropriate. All emitters with individual control, modulating where appropriate.	Segregated local gas-fired water heaters or electrical point-of-use units.	Full checks on system operation and calibration. All commissioning settings tagged. System monitoring under different load conditions.	As level 1.	As Level 1 plus system designed to be easily maintainable.	ROI 2 - 4 years. -20% energy used.	Highly recommended for minimum energy usage.
1	Optimiser plus time control of zones where appropriate. Time control of HW storage.	Effective boiler sequence control Simple but effective boiler control strategies. High efficiency/ condensing boilers.	Compensated with space tempaterature reset. Separate compensated circuits for orientation, structure & occupancy. Distribution losses minimised at low load.	TRVs & room themostats except in room with space reset sensor.	Segregated HWS system. Top located or dual thermostats on HWS calorifiers if segregation not possible.	Full checks on system operation and calibration. Seasonal checks.	As level 0 plus descriptive write up of system concept and operation. Logic diagrams.	Full checks including calibration twice p.a.	ROI 1 - 2 years. -10% energy used.	Recommended for cost effective energy savings.
0	Optimiser plus time control of HW storage.	Effective boiler sequence control.	Compensated with space temperature reset.	None or on emitters designed for separate control.	Effective thermostats on HWS calorifiers.	Full checks on system operation and calibration.	Full manufacturers literature. Full record wiring diagrams etc.	Annual checks of basic control and system operation.	Base Energy usage.	Minimum legally required for new buildings since 1985.
-1	Timeswitch.	Ineffective or no boiler sequence control.	Not compensated.	None or TRVs.	Ineffective or poorly located thermostats.	Checks made to ensure heat supplied. Basic control.	Minimal information.	Breakdown maintenance only.	Up to 50% additional energy use.	Does not meet building regulations since 1985.

Table 3 Heating controls: Output less than 100 kW

Band Level	Time Controls	Boiler Controls	Disribution System Controls	Space Heating Controls	HWS Controls	Commissioning	Documentation	Maintenance	Marginal ROI (Return on Investment) & Energy Usage	Comments
1	Optimiser plus time control of zones where appropriate. Time control of HW storage.	Effective boiler sequence control where appropriate. Simple but effective boiler control strategies. High efficiency/ condensing boilers.	Compensated with space tempateraturе reset. Separate compensated circuits for orientation, structure & occupancy if wide variations in load/use.	TRVs & room thermostats except in room with space reset sensor. Interactive control of rooms where appropriate.	Segregated HWS system. Top located or dual themostats on HWS calorifiers if segregation not possible.	Full checks on system operation and calibration Seasonal checks.	As level 0 plus descriptive write up of system concept and operation. Logic diagrams.	Full checks including calibration twice p.a.	ROI 1 - 2 years. -10% energy used.	Recommended for cost effective energy savings.
0	Effective time control plus time control of HWS storage.	Effective boiler thermostats.	Compensated with space temperature reset.	None or on emitters designed for separate control.	Effective themostats on HWS calorifiers.	Full checks on system operation and calibration.	Full manufacturers literature Full record wiring diagrams etc.	Annual checks of basic control and system operation.	Base Energy usage.	Minimum legally required for new buildings since 1985.
-1	Timeswitch.	Boiler thermostats.	Not compensated.	None or TRVs.	Ineffective or poorly located themostats.	Checks made to ensure heat supplied. Basic control.	Minimal information.	Breakdown maintenance only.	Up to 50% additional energy use.	Does not meet building regulations since 1985.

DESIGN, SPECIFICATION, INSTALLATION AND COMMISSIONING

- *Design*
  The design of control systems can have a substantial effect on the energy efficiency of the plant. Typically, savings of 20% or more will result from a high level of control compared with a basic level. The extra investment required for the high level will normally be returned within two to four years.
- *Specification*
  Controls specification should cover what is required in sufficient technical and descriptive detail to ensure that the document is precise. In particular, sensor location should be detailed and the general good practice standards for installation and location of control devices should be specified.
- *Installation*
  Faults occurring at the installation stage should be identified during commissioning; in practice many are not. It is, therefore, desirable to maintain as close control as possible at this stage, to lessen the chances of faults being present in the operating system. Some key points are:
  - clarify the apportioning of responsibility between mechanical and electrical contractors and consultants;
  - maintain communication between mechanical and electrical contractors through regular meetings;
  - fit adequate instrumentation to enable accurate commissioning and subsequent assessment to ensure efficient operation.
- *Commissioning*
  Ideally, control commissioning should be carried out by the controls system suppliers, or others who have been on the appropriate training course. Commissioning falls into three areas:
  - Pre-commissioning: when the controls installation is complete, the sequence of operation, valve and damper operation and set-points should be checked.
  - Commissioning: the main plant must be commissioned and operated prior to the controls being commissioned. When this has been done, the controls should be calibrated and adjusted to provide stable design conditions.
  - Post-commissioning: stability of operation under varying climatic conditions should be checked. Two post-commissioning visits during the first year are recommended.

14 CONTROL MAINTENANCE

Once a system is installed and correctly set up, it is easy to expect that the controls will continue to yield the intended energy savings. However, without regular maintenance and checking, the system will gradually become less efficient. Common problems include: sensing elements getting dirty; controls being overridden and not reset; and mechanical failure of valves, thermostats, etc.

SOURCES OF FURTHER READING AND INFORMATION

It is recommended that a programme of regular maintenance is undertaken which includes the following checks:

- Have any controls been tampered with or overridden?
- Are the controls still correctly calibrated?
- Do all the components function correctly?
- Is the building environment still regarded as comfortable?
- Have any changes of use occurred to warrant changes in the system?
- Will all safety devices operate in an emergency?

A comprehensive energy management system will provide data on energy use that should highlight problems as they occur.

15 SUMMARY

Good control of building services can produce significant energy savings. Installation of appropriate control equipment will usually pay back within two years and often much quicker. However, it is important that the energy efficiency of both equipment and control systems is considered at the design and installation stages - mistakes can be difficult to rectify later.

The control system should be appropriate to the various uses of the building. Zoning is essential to minimise energy use in intermittently occupied areas or those with different levels of activity. Careful consideration should be given to the level of complexity required. The control system should be kept simple unless some quantifiable benefit can be gained by complexity.

For energy savings to be achieved over a period of time, it is essential that the equipment and the control system are properly maintained. Time switches, programmes and set-points should be checked regularly to ensure that they have not been altered. The control system should be adjusted when changes of use of the building occur.

A Building Energy Management System will only work effectively if the users are committed to it and appropriate expertise is available.

16 SOURCES OF FURTHER READING AND INFORMATION

- **Department of the Environment Publications:**

Energy Efficiency in Buildings Information Leaflets:

20. *Specifying and Selecting a Building Management System*
21. *Expert Systems and BEMS*

Fuel Efficiency Booklets:

9. *Economic Use of Electricity in Buildings*
12. *Energy Management and Good Lighting Practices*

Good Practice Guides:

15. *Energy Efficiency Refurbishment of Public Houses Sector File*
28. *Energy Audit and Survey Guide for Building Managers and Engineers*
33. *Energy Efficiency in Offices - Understanding Energy use in your Office*
46. *Energy Efficiency in Offices - Heating and Hot Water Systems in Offices*
71. *Selecting Air Conditioning Systems - A Guide for Building Clients and their Advisors*

SOURCES OF FURTHER READING AND INFORMATION

Energy Consumption Guides:

10. *Energy Efficiency in Offices - Guide for Senior Managers*
19. *Energy Efficiency in Offices - A Technical Guide for Owners and Single Tenants.*

Copies of the above publications and further information on energy efficiency in buildings are available from:

Enquiries Bureau
BRECSU
Building Research Establishment
Garston
Watford
WD2 7JR
Tel: 01923 664258
Fax: 01923 664787

Energy Technology Series 1: *Energy Management Systems*

Copies of the above publication and further information on energy efficiency in industry are available from:

Energy Efficiency Enquiries Bureau
ETSU
Harwell
Didcot
Oxfordshire
OX11 0RA
Tel: 01235 436747
Fax: 01235 433066

■ **General reference:**

- *Automatic Controls and Their Implications for Systems design* - AM1 CIBSE 1985
- Health and Safety Executive Guidance Note PM5 (*Recommendations for locations and settings of boiler controls and high limit thermostats*)
- Standard Specification for Control Components - National Engineering Specifications: January 1989

■ **The latest news in energy efficiency technology**

Energy Management is a free journal issued on behalf of the DOE which contains information on the latest developments in energy efficiency, and details of forthcoming events designed to promote their implementation. It also contains information addresses and contacts for the regional Government Offices.

Copies of *Energy Management* can be obtained through:

Emap Maclaren Ltd
Maclaren House
19 Scarbrook Road
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Surrey
CR9 1QH

APPENDIX 1 THE BUILDING REGULATIONS

THE BUILDING REGULATIONS

The 1990 Building Regulations contain the same requirements for heating and ventilation (H&V) control as stated in the 1985 regulations. The regulations do NOT apply to:

- systems which heat or store water for the purpose of an industrial process;
- systems provided to serve a building which does not exceed 125m^2 in floor area;
- individual appliances with an output rating of 10 kW or less.

The H&V control requirements are contained in section L4 of the 1990 Building Regulations. The requirements are detailed below. The wording has been re-ordered and changed slightly to improve clarity. An interpretation of the general requirements of the Regulations is given at the end of this Appendix.

Building Regulations are modified periodically. Compliance with current Regulations should be checked at the time of design.

Building Regulations Requirement L4

General

Paragraph L4 - Space heating or hot water systems in buildings shall be provided with automatic controls capable of controlling the operation and output of space heating systems and the temperature of stored water.

Acceptable Levels of Performance

0.1 Any controls described below will meet the requirements of paragraph L4.

0.2 Controls should be capable of regulating the output of space heating systems and the temperature of stored water to meet conditions normal for the intended use of the building.

Time Control for Intermittently Heated Buildings

- A time switch is the minimum level of control where the space heating system output is 100 kW or less.
- An optimiser is required where the space heating system output is more than 100 kW.

Controls which override the time switch or optimiser to provide a small amount of heat, may be provided to prevent damage to the building structure, services, or contents, by frost, excessive humidity or condensation.

Boiler Sequence Control

Boiler controls are required to achieve efficient operation where two or more gas or oil fired boilers, with a total load of more than 100 kW, are connected to supply the same heat demands. Boilers run most efficiently at, or near, full output, and control should be provided in a form which can detect variations in the need for heat in a building and so start, stop or modulate the boilers as needed (sequence control). Care is needed in hydraulic design to ensure stable control.

System Temperature Control

Where the space heating system uses hot water, a temperature sensitive device (weather compensating control) should be provided outside the building to regulate the temperature of the water flowing in the heating circuit.

APPENDIX 1 THE BUILDING REGULATIONS

Room Temperature Control
Thermostats, thermostatic radiator valves, or any other equal form of temperature sensing, should be provided for each part of the space heating system designed to be separately controlled.

Hot Water Storage Control
All hot water storage vessels should have a thermostat to keep the water at the required temperature.

Hot water storage vessels with a capacity greater than 150 litres should have a time switch to shut off the supply of heat when there is no hot water demand. This does not apply to vessels heated by off-peak electricity.

Interpretation of the General Requirements of the Building Regulations
The general requirements of the regulations are good practice. The following notes clarify application of the regulations:
Continuously occupied buildings may be heated at all times. However, in buildings such as old peoples' homes and hospitals, the temperature requirements should generally be lowered overnight. This results in substantial energy savings.

The wording of the room temperature control section, stating "for each part of the space heating system designed to be separately controlled" means that space temperature should be controlled.

Where a number of rooms form a zone with similar characteristics, either of the following should meet the intent of the regulations.

- control of the zone via a zone control system
- space temperature reset of a compensator serving that zone only.

Acceptable Levels of Performance Item 0.2 indicates that for normal use of a building, methods of control other than those described may be used. This should be treated with caution, and only where the building or system is significantly different to the norm should other methods be used. Obviously justification of other methods may be necessary. Where legislation or good practice guidance requires the use of other methods, there should be little difficulty in justifying their use. A case in point is the storage of hot water above a minimum temperature at all times to avoid the effects of legionella.

Titles in the Fuel Efficiency Booklet series are:

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14 *Economic use of oil-fired boiler plant*
15 *Economic use of gas-fired boiler plant*
16 *Economic thickness of insulation for existing industrial buildings*
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Fuel Efficiency booklets are part of the Energy Efficiency Best Practice programme, an initiative aimed at advancing and promoting ways of improving the efficiency with which energy is used in the UK.

For copies of Fuel Efficiency booklets or further information please contact the addresses below.

Overseas customers please remit £3 per copy (minimum of £6) to the ETSU or BRECSU address with order to cover cost of packaging and posting. Please make cheques, drafts or money orders payable to ETSU or BRECSU, as appropriate.

The Department of the Environment's Energy Efficiency Best Practice programme provides impartial, authoritative information on energy techniques and technologies in industry and buildings. This information is disseminated through publications, videos and software, together with seminars, workshops and other events. Publications within the Best Practice programme are shown opposite.

For further information on:

Buildings-related topics contact:
Enquiries Bureau
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